Research and Development of a Proton Exchange Membrane Fuel Cell, Hydrogen Reformer, and Vehicle Refueling Facility

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Objectives

- Design, develop, and demonstrate small on-site H_2 production system for stationary fuel cells and H_2 fuel stations.
- Design, construct, and operate a multipurpose refueling station to dispense H_2/CNG blends and pure H_2.
- Design, construct, install and operate a H_2-fueled stationary 50-kW fuel cell.
- Maintain safety as a top priority in the design and operation of the fueling station and fuel cell.
- Evaluate operability, reliability, and economic feasibility of integrated power generation and vehicle fueling system.
- Obtain adequate operational data on fuel station to provide basis of future commercial fueling station designs. Develop appropriate "standard" designs for commercial applications.

A related goal, beyond the scope of the current project, is to expand the current "Energy Station" facility to serve as the first commercial facility when sufficient hydrogen demand develops. A vision is to have this facility ultimately serve as a link in an emerging regional/national H_2 corridor.

Technical Barriers

This project addresses the following technical barriers from the Technology Validation section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year R,D&D Plan:

- C. Hydrogen Refueling Infrastructure
- E. Codes and Standards
- I. Hydrogen and Electricity Coproduction

Approach

- Several small-scale natural gas based fuel processing technologies under development by others were tested in the laboratory and field environments prior to and during the period of the current project. These included partial oxidation (POX), autothermal reforming (ATR), and steam methane reforming (SMR) technologies.
- POX technology was eliminated from further consideration prior to the start of the current project.
- The ATR and SMR fuel processors were integrated with small-scale pressure swing adsorption (PSA) systems and tested extensively.

- Based on the experience from the testing and on the results of an economic analysis, the final technology selection was made.
- The 50-kW fuel cell stack design was based on existing 7.5-kW reformate-based stack modules developed for residential power generation. Modifications were made to allow operation on pure hydrogen.
- Fuel station design was based on previous experience gained from over 15 H_2 and H_2/CNG fuel stations. The ability to dispense various blends of H_2 and CNG is provided for in the design.
- Extended duration operation of the fully integrated hydrogen generation, fuel cell, fuel station system will be conducted to address robustness, performance, and economic feasibility of this "Energy Station" concept.

Accomplishments

- Based on extensive test results and an economic analysis, SMR technology was selected for the fuel processor.
- An SMR fuel processor from Harvest Energy Technologies integrated with a PSA system from QuestAir Technologies was installed and started up at the Las Vegas site in August 2002. The unit operated well and achieved H_2 product purity in excess of 99.95%.
- The multipurpose fuel station was commissioned in July 2002 (started up with delivered liquid hydrogen). CNG/H_2 and H_2 fuel dispensing have been successfully performed on a fueling test rig, CNG/H_2 internal combustion engine (ICE) vehicles and H_2 fuel cell vehicles.
- The 50-kW stationary fuel cell was started up in August 2002 on hydrogen supplied by the SMR unit.

Future Directions

- Begin extended unattended operation of the stationary fuel cell.
- Achieve extended integrated operation of the reformer, fuel cell and fuel station.
- Collect site performance data to assess overall operation of the system.
- Build up vehicle fleet to include 6 H_2/CNG buses and several light duty vehicles. This is dependent on a separately funded effort.

Introduction

Small-scale on-site hydrogen production technology that can operate on readily available fuels such as natural gas will be required to provide hydrogen fuel stations in certain locations where delivered hydrogen is not readily available. However, small-scale natural gas based hydrogen reformers are not fully developed and will suffer from poor economics due to their small scale and due to poor utilization rates in the early years of hydrogen vehicle development. One approach to achieving high utilization rates of the reformer is to baseload it with a stationary fuel cell that produces electric power while the intermittent vehicle-fueling load is handled by diverting a portion of the hydrogen from the fuel cell to the fuel station as and when needed. This co-production of hydrogen fuel and electric power is referred to as an "Energy Station". The objective of this project is to demonstrate the technology and validate the commercial viability of an alternative fuel station for dispensing blends of hydrogen and compressed natural gas (CNG) and pure hydrogen to vehicles, and the co-production of electricity from a stationary fuel cell. A team of three organizations-Air Products and Chemicals Inc., Plug Power Inc., and the City of Las Vegas-come together to develop, design, procure, install, and operate this "Energy Station" in Las Vegas, Nevada. This refueling station includes onsite hydrogen generation equipment supplied by Air Products and a stationary fuel cell powered electric generator

supplied by Plug Power under a subcontract. The City of Las Vegas (CLV) is providing the site location and the operating and maintenance staffing for the refueling station. The DOE cooperative agreement covers a five-year nominal period (1999-2004) for development, design, installation, startup, and operation of the refueling station.

Figure 1 is a block diagram of the proposed refueling facility. In addition to the on-site hydrogen generation, a standard merchant liquid hydrogen supply system (liquid hydrogen storage tank and vaporizers) was installed to satisfy initial demand for hydrogen at the refueling station and to provide back-up supply for additional system reliability. The hydrogen compression, storage, blending and dispensing systems are capable of supplying pre-determined blends of H_2 and CNG to be dispensed to trucks and buses with ICEs converted to run on H_2/CNG mixtures. The station will also be able to dispense pure hydrogen to vehicles. Currently there are one light duty vehicle (LDV) and one para-transit bus fueled with the CNG/H_2 blend. The fuel cell operates on pure hydrogen to generate electric power, which is put back on the local power grid. The fuel cell will be operated to balance the hydrogen demand on the hydrogen generator for vehicle refueling.

Upon successful testing/operation of the first CNG/H_2 fueled para-transit bus, CLV will proceed to convert six new CNG fueled buses to CNG/H_2 blended fuel operation. They expect to have all six buses converted over a six-month period, nominally one bus per month through December 2003. H_2 demand growth is expected to continue as additional buses and light duty vehicles are converted to the alternative fuels over the remaining two years of the demonstration project. It is also proposed that a natural gas-based onsite hydrogen generator will be installed and operated at the refueling station.

Should the alternative vehicle refueling demonstration station prove to be successful, it is anticipated that vehicle fleets would continue to grow.

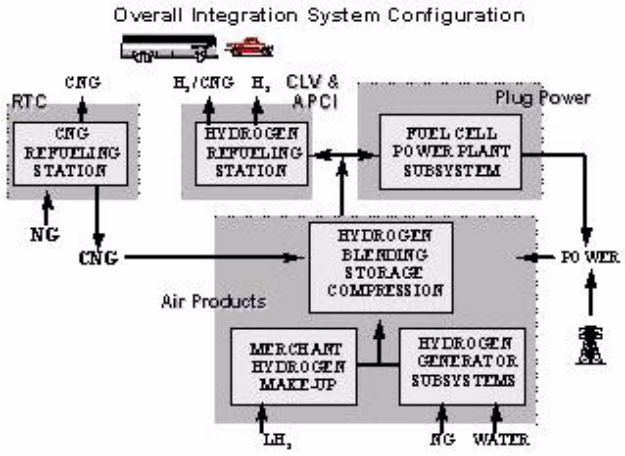

Figure 1. Overall Integration System Configuration

Approach

Air Products evaluated various small-scale developmental natural gas reformation technologies via extensive laboratory and field testing. These technologies included partial oxidation, autothermal reforming and steam methane reforming. These test results were the basis for technology selection for the fuel processor. The fuel processor was integrated with a PSA system supplied by QuestAir to develop the on-site system capable of generating pure hydrogen from natural gas.

The 50-kW fuel cell was built by assembling eight 7.5-kW residential fuel cell stacks developed by Plug Power for the residential power market. The residential system was designed to operate on reformate; thus, modifications were required for the pure hydrogen service in this project. Extensive testing of the fully-assembled module at Plug Power's Latham, New York, facility was conducted to qualify individual systems and the final system configuration.

Results

Hydrogen Generator. The hydrogen generator (see Figure 2) was installed, commissioned and placed into

Figure 2. View of the Hydrogen Generator (Left) and Fuel Cell (Right)

operation in the summer of 2002. On-spec hydrogen production, with purity in excess of 99.95%, was established in August 2002. Successful process operation of the hydrogen generator was achieved without process modification to the system after ex-works delivery of the unit to the site for operation.

Since the initial establishment of hydrogen production, the unit has achieved an aggregate run-time of over 2200 hours. The integrated hydrogen generator system controls have been demonstrated to achieve the full range of expected operability control. The hydrogen generator is capable of one-button start, with automated start-up ramping and subsequent load following capability. The hydrogen generator can be, and is, operated remotely, including remote start-up where the appropriate control permission exists based on the automated system's diagnosis of the unit status. In other words, the system is engineered to recognize the potential of conditions from a shutdown mode that necessitate a physical check prior to restart. Consequently, the system can also recognize the safe condition from which a remote start can be initiated via telemetry with the appropriate control program interface. Consistent with this, remote operation and monitoring of the hydrogen generator has been demonstrated during this period.

Produced hydrogen has been utilized for electrical power production by the fuel cell power plant, as well as for fueling of ICE vehicles with H_2/CNG blends and fuel cell vehicles with hydrogen when required.

The fuel cell continues to establish the majority of demand for the on-site generated hydrogen during fuel cell availability. The availability of the fuel cell, however, has not been highly reliable. As expected, vehicle-fueling demand is insufficient for utilization of the full hydrogen generator production capacity. The fuel cell has been able to present a demand for the produced hydrogen during the anticipated fleet build-up period.

Fueling Station. Operation of the fueling station was established in July 2002. The fueling station segment of the Energy Station consists of liquid hydrogen storage, gaseous hydrogen storage, product compression, CNG/H_2 fuel blending, and CNG/H_2 and hydrogen fuel dispensing (see Figure 3).

The CNG/H_2 fuel dispensing was tied into the City of Las Vegas's fuel consumption accounting system for seamless accounting with their existing fleet of CNG vehicle operations.

Since operation of the fueling station was established, satisfactory vehicle fueling functionality has been demonstrated. Fueling operations have been performed for both hydrogen fuel cell vehicles as well as blend CNG/H_2 internal combustion engine vehicles.

Fully integrated control functionality of the Energy Station has been demonstrated.

Stationary Proton Exchange Membrane (PEM) Fuel Cell . The 50-kW PEM fuel cell was initially started up in August 2002, and a continuous run time of 160 hours was logged. The unit successfully ran for three days before it was tripped by the reformer. It was restarted successfully and ran another three days before it was tripped due to single cell failure.

Several operational issues were identified and fixes implemented:

- Scanning of individual cell voltage was unreliable and was traced to a design issue with the cell scanner approach in multiple-stack configurations. The scanner cards were redesigned, successfully installed, and operational in April 2003.
- There was inadequate draining of water from multiple stacks with a common drain. The water

Figure 3. View of the Fuel Station

drain valve was successfully modified in April 2003.

Following these fixes, the unit continued to have operational issues with cell voltage falloff that made continuous operation an issue. This issue appears to fault the concept of multiple stacks with no provision to accommodate the need of each stack with respect to voltage output, over stoichiometric flows to both anode and cathode, humidity of both anode and cathode, and temperature of each stack. The fuel cell stack will be replaced during the week of July 16, 2003, and will be restarted.

A possible issue with timing of electric load shedding on shutdown has been identified. The timing will be analyzed and software and/or hardware modifications made to eliminate potential ground looping, which may be contributing to stack failures.

Conclusion

- The Energy Station is a viable operational concept. The fuel cell has provided a demand for hydrogen during the initial stages of fleet build-up with low levels of vehicle fueling demand.
- Integrated control functionality is critical to system-wide reliability and operability.
- Vehicle fleet build-up continues to be a primary challenge to satisfactory utilization of hydrogen fueling infrastructure efforts.
- The fuel cell design approach of multiple stacks with no ability to independently manage gas flows, temperature, humidity and power is in question.
- An excellent list of lessons learned has been compiled. Additional lessons learned from Plug Power single-stack 5-kW systems will be combined in future designs.
- Current operating performance predicts we will meet the 2-3 months operation with minor tweaks.

FY 2003 Publications/Presentations

Presentations on the "Energy Station" concept and the Las Vegas project have been given to various audiences separately or in conjunction with a discussion of developing hydrogen infrastructure, including:

1. Hydrogen Expo 2002, Hamburg, Germany, October 10-12, 2002 - "Pathways to Building Infrastructure to Support the Hydrogen Economy"

2. U.S. - Australian Climate Action Partnership Opportunities Roundtable, Washington, DC, November 4, 2002 - "Role of Hydrogen as an Energy Resource for the United States"

3. Hydrogen Energy Systems Society of Japan Symposium, Tokyo Institute of Technology, Tokyo, Japan, December 11, 2002 - "Hydrogen Economy Strategies- a U.S. Perspective"

4. SAE Telephone/Webcast, April 3, 2003 - The Path to the Emission-Free Vehicle through the Use of Hydrogen as a Fuel - "Hydrogen Fuel Infrastructure - Creating the Future"

Special Recognitions & Awards/Patents Issued

1. Special Member award from the National Hydrogen Association for " … development of the Las Vegas Refueling Station, the world's first energy station featuring the co-production of hydrogen and electricity …"